Electron transport in a slot-gate Si MOSFET

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The transversal and longitudinal resistance in the quantum Hall effect regime was measured in a Si MOSFET sample in which a slot-gate allows one to vary the electron density and filling factor in different parts of the sample. In case of unequal gate voltages, the longitudinal resistances on the opposite sides of the sample differ from each other because the originated Hall voltage difference is added to the longitudinal voltage only on one side depending on the gradient of the gate voltages and the direction of the external magnetic field. After subtracting the Hall voltage difference, the increase in longitudinal resistance is observed when electrons on the opposite sides of the slot occupy Landau levels with different spin orientations.

I. INTRODUCTION

The fabrication of Si-MOSFET samples with a narrow gate barrier or with narrow slots in the gate [1, 2, 3, 4, 5] has given rise to new experimental possibilities. In particular, samples with a narrow gate barrier [1, 2] were used for investigation of the backscattering of the edge current in the quantum Hall effect (QHE) regime, while the slot-gate geometry has permitted reliable measurements of a two-dimensional electron transport in case of low electron density [6]. In this work, we use the slot-gate geometry to measure the longitudinal resistance R_{xx} in the QHE regime for unequal electron densities along the sample. Our aim was to reveal the influence of the spin-flip process on the electron transport when electrons on the opposite sides of the slot occupy Landau levels (LL) with different spin orientations.

II. EXPERIMENTAL RESULTS AND DISCUSSION

The sample with two narrow slots (100 nm) in the upper metallic gate was similar to that described earlier in Ref. [6] (see insert in fig. 1). Application of different gate voltages V_{G} to the gates G_1, G_2 and G_3 permitted one to maintain different electron densities n in different parts of the sample.

The sample resistance was measured at $T = 40\,\mathrm{mK}$ using a standard lock-in technique with the measuring current 20 nA at a frequency of 10.6 Hz. The electron mobility was $\mu = 2.68\,\mathrm{m}^2/\mathrm{V}\cdot\mathrm{s}$ at $n = 0.83\cdot 10^{16}\,\mathrm{m}^{-2}$.

In the first series of experiments, all gates were connected. The magnetic field dependences of the Hall (transverse) resistance R_{xy} measured between probes V_2–V_7 are shown in fig. 1*a*. The "plateaus" are clearly seen only for Landau filling factors $\nu \equiv hn/eB = 4$ and $\nu = 6$ corresponding to the Hall resistances $6.45\,\mathrm{k}\Omega = 1/4(h/e^2)$ and $4.3\,\mathrm{k}\Omega = 1/6(h/e^2)$, correspondingly. Clear "plateaus" in R_{xy} at $\nu > 6$ are usually not observed in Si-MOSFET being "contaminated" by the "overshoot" effect [7, 8].

The longitudinal resistance R_{xx} was measured across the gap between voltage probes V_1 and V_2 (R_{12}) and without the gap, between probes V_2 and V_3 (R_{23}). In zero magnetic field, R_{12} is 1.5 times larger than R_{23} (fig. 1*b*) due to the distance between probes 1 and 2 being 1.5 times larger than that between probes 2 and 3. Therefore, the longitudinal resistance is not affected by the existence of the narrow slot in the gate. In other words, in our sample, the narrow slot in the upper gate does not lead to the existence of a potential barrier. It is remarkable, however, that at magnetic fields above 10 T, both resistance curves merge. This can be explained by the influence of the edge channels [9, 10], so that the length between probes becomes irrelevant.

In case of different gate voltages $V_{\mathrm{G1}} \neq V_{\mathrm{G2}}$ (V_{G3} was always equal to V_{G2}), the difference in the transverse Hall voltages $\Delta V_{\mathrm{H}} \equiv V_{18} - V_{27}$ appears. ΔV_{H} is added to the longitudinal voltage V_{xx} only on one side of the sample, depending on the gradient of the gate voltage ∇V_{G}, which makes the longitudinal resistance non-symmetric: for $V_{\mathrm{G1}} < V_{\mathrm{G2}}$ at given direction of the magnetic field $\mathbf{B}$, ΔV_{H} was added to the voltage V_{12}, while for $V_{\mathrm{G1}} > V_{\mathrm{G2}}$, V_{12} remains unchanged (fig. 2*a,b*). On the opposite side of the sample, the situation is reverse: ΔV_{H} is added to the voltage drop V_{87} for $V_{\mathrm{G1}} > V_{\mathrm{G2}}$. It was shown in Ref. [3] that the sample side where ΔV_{H} is added to V_{xx} is determined by the vector product $\mathbf{B} \times \nabla V_{\mathrm{G}}$. Different values of V_{xx} on the opposite sides of the sample mean that in order to analyse the longitudinal resistance in the case of different gate voltages, one need to subtract properly the contribution of the Hall voltage difference.

In another set of experiments, conducted at $T =$

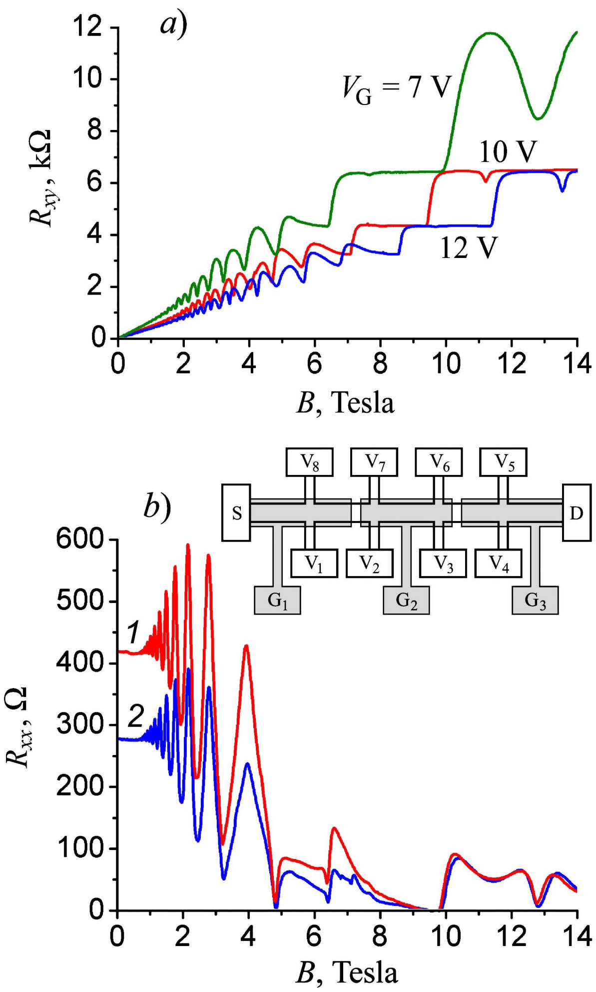

FIG. 1: a — transverse resistance R_{xy} as a function of magnetic field at fixed gate voltages $V_{\rm G} = 7, 10, 12\,$V; b — longitudinal resistance R_{xx} measured between probes V_1 and V_2, R_{12} (*1*) and between probes V_2 and V_3, R_{23} (*2*) at $V_{\rm G} = 7\,$V. The insert shows the schematics of the slot-gate sample.

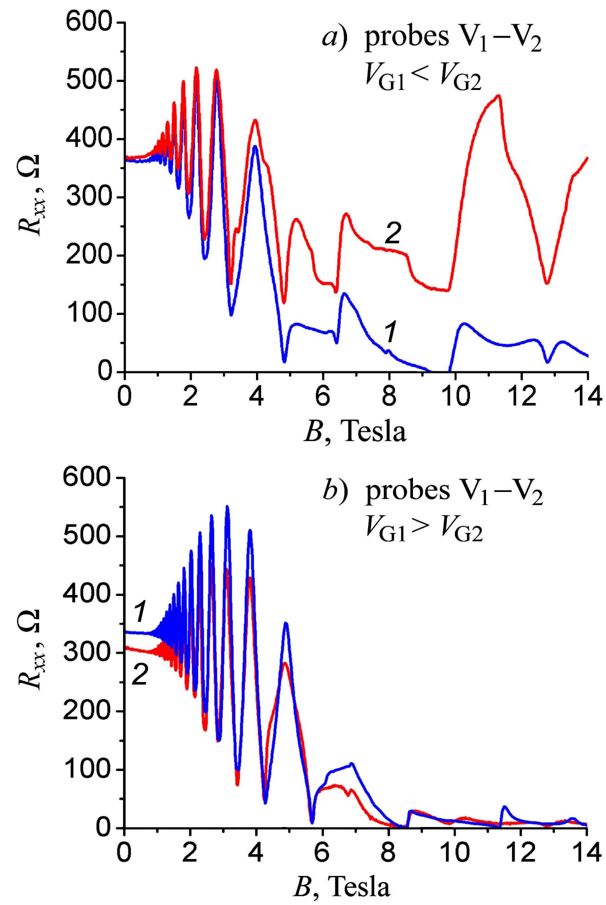

FIG. 2: Longitudinal resistance R_{12} measured when $V_{\rm G1} \neq V_{\rm G2}$. a — R_{12} measured when $V_{\rm G1} < V_{\rm G2}$ ($V_{\rm G1} = 7\,$V, $V_{\rm G2} = 12\,$V) (curve *2*); R_{12} for the case of equal gate voltages $V_{\rm G1} = V_{\rm G2} = 7\,$V is shown for comparison (curve *1*); b — R_{12} measured when $V_{\rm G1} > V_{\rm G2}$ ($V_{\rm G1} = 12\,$V, $V_{\rm G2} = 7\,$V) (curve *2*), R_{12} for the case of equal gate voltages $V_{\rm G1} = V_{\rm G2} = 12\,$V is shown for comparison (curve *1*).

300 mK, the magnetic field was fixed at 8 Tesla, while the gate voltage was varied. First, all gates were connected and $V_{\rm H}$ was measured between probes V_1 and V_8 (figure 3, blue line). Using the data shown in fig. 1a, one can conclude that the “plateau” at around $V_{\rm G} = 10\,$V corresponds to the filling factor $\nu = 6$, while the “plateaus” at around $V_{\rm G} = 7\,$V and $V_{\rm G} = 13\,$V correspond to $\nu = 4$ and $\nu = 8$, correspondingly.

Figure 4a shows V_{xx} measured simultaneously on both sides of the sample between probes V_1–V_2 and probes V_8–V_7. $V_{\rm G2} = 10\,$V was kept constant, while $V_{\rm G1}$ was varied from 5 V to 15 V. In this experiment, the gradient of the gate voltage undergoes a sign change at $V_{\rm G1} = 10\,$V. If the direction of the magnetic field is reversed, the curves trade places. The difference between the two curves ΔV_{xx} plotted as a function of $V_{\rm G1}$ (fig. 3, red line) practically coincides with $V_{\rm H}(V_{\rm G1})$. This fact allows us to subtract properly the contribution of the Hall voltage difference: one need to take into account only the lower parts of the both curves. The result is shown in fig. 4b.

Let us discuss the curve shown in fig. 4b. Keeping constant $V_{\rm G2} = 10\,$V means that electrons underneath the gate G_2 always occupy the sixth LL with spin “down” (see fig. 3 and the inset). When $V_{\rm G1}$ is varied from 9 V to 11 V, electrons across the slot occupy the same (6th) LL and, therefore, have the same spin orientation. However, when 7 V< $V_{\rm G1}$ <9 V and 12 V< $V_{\rm G1}$ <14 V, the electrons underneath the gate G_1 occupy “spin up” LLs 4 and 8, correspondingly. At both filling factors $\nu = 4$ and 8 (indicated in the figure by arrows), the longitudinal resistance increases compared to the $\nu = 6$ case. Possible reason for this resistance increase is some additional scattering [11, 12] due to the necessity for electrons to flip their spins when crossing the slot.

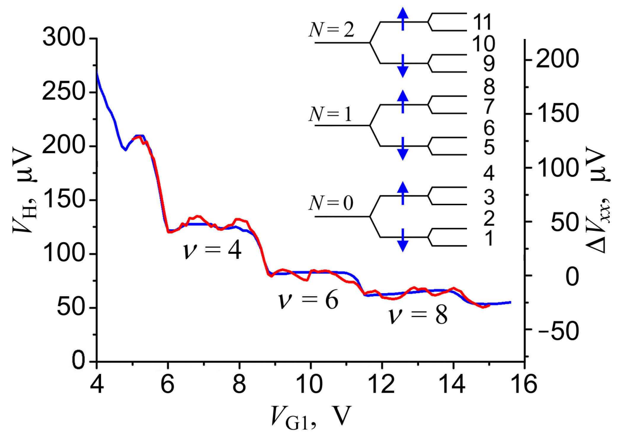

FIG. 3: Dependence of the Hall voltage V_H on the gate voltage at fixed magnetic field $B = 8\,\mathrm{T}$ (blue line, left scale). The inset shows distribution of Landau levels in a Si-MOSFET with cyclotron, spin and valley splittings indicated. Numbers correspond to the integer values of the filling factor ν. The difference of the longitudinal voltages measured on the opposite sides of the sample $\Delta V_{xx} = V_{87} - V_{12}$ is plotted as a function of V_{G1} at fixed $V_{G2} = 10\,\mathrm{V}$ for comparison (red line, right scale).

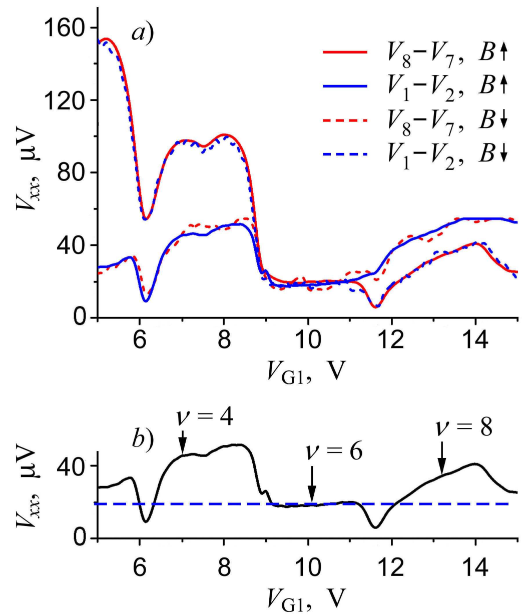

FIG. 4: a — longitudinal voltages across the slot V_{87} and V_{12} as a function of V_{G1} at fixed $V_{G2} = 10\,\mathrm{V}$ and $B = 8\,\mathrm{T}$, b — lower part of the curves: no contribution of the Hall voltage difference.

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